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To: Mr. A.W. Beck
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EXCITATION SYSTEM TESTS - MOUNTAIN CHUTE GS

G.R. Bérubé

Tests were performed on ASEA static excitation systems installed at Mountain Chute GS in an attempt to establish the causes of unexplained failures which occurred on unit G2 during 1990 and early 1991. A number of separate problems were uncovered which appear to explain some of the erratic behaviour of the G2 excitation system over the past year. During the course of the tests a serious unreported problem was uncovered on G1 which may temporarily limit the acceptable operating range of this unit. Resolving this problem will require further analysis and possibly additional field measurements.

1. BACKGROUND

Mountain Chute GS consists of two 75 MVA hydraulic units equipped with static excitation systems manufactured by ASEA and power system stabilizers supplied by the Ontario Hydro Research Division. The units were originally commissioned in 1969; the results of the excitation system acceptance tests and the stabilizer design, installation and commissioning are documented in references /1/ and /2/.

During the latter part of 1990 and early 1991, unit 2 began to suffer a number of problems related to misoperation of the excitation system. Operations staff noted several instances during which there were intermittent variations in terminal voltage and reactive power on the generator and on a number of occasions the unit was automatically removed from service due to excitation system failure. During the course of troubleshooting these failures, the local Protection and Control (P&C) staff identified and rectified a number of problems including a faulty Test/Service switch which controls the supply of ac voltage to the exciter electronics. Despite these efforts the unit continued to suffer intermittent failures. On March 20, 1991 the unit was declared unavailable due to excitation problems and the Research Division was requested to assist the local P&C staff in identifying the source of the failure. On-line tests were also performed to assess the condition of the power system stabilizing equipment.

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1.1 Excitation System Description

Each static exciter at Mountain Chute consists of a series connection of a controlled converter (thyristor bridge) and an uncontrolled rectifier (diode bridge) as depicted in the simplified schematic of Figure 1. At rated terminal voltage the uncontrolled rectifier supplies an output direct voltage of just under 300 Vdc. The total voltage supplied to the field winding is controlled by adjusting the firing angle of the controlled bridge to add or subtract voltage as required. Since the generator's field voltage requirement is normally below the voltage supplied by the uncontrolled rectifier, the thyristor bridge typically operates as an inverter; ie. negative dc voltage and positive dc current. Five parallel bridges are provided at this installation and the continuous rating of the overall system is 1600 Adc. Each leg of each thyristor bridge consists of a pair of series connected thyristors, resulting in a total of sixty thyristors for the overall assembly.

The automatic voltage regulator (AVR) is of a straightforward design and is depicted, in block diagram format, in Figure 2 (reproduced from reference /1/). The AVR gain (shown as K_A in Figure 2) may be switched to one of the five settings listed in Table 1 (Note: these values supersede those reported in reference /1/.) The normal in-service setting for both of the units at Mountain Chute GS is switch position 3; all measurements were performed with the AVR gain switch at this position unless otherwise indicated.

Table 1 ASEA EXCITERS - MOUNTAIN CHUTE GS

Switch Position	AVR Gain (pu E_{fd} [1]/pu $E_{t\text{-}ref}$)
1	80
2	120
3	180
4	260
5	400

NOTE: (1) Base field voltage = 108 Vdc

Also shown in Figure 2 are the integrated power stabilizer and terminal voltage limiter circuits. The normal stabilizer gain setting for these units is 13.2 pu $E_{t\text{-}ref}$/pu ω. The terminal voltage limiter circuit is set to begin operating at 115% of rated terminal voltage.

2. OFF-LINE MEASUREMENTS

Prior to our arrival at the station the local staff had performed a number of measurements on the exciter and had verified the integrity of all thyristor fuses and of the connections to each thyristor. The thyristor bridges and their associated control circuitry were the focus of the troubleshooting efforts since a number of previous failures, including a failed start-up attempt after the most recent failure, were associated with operation of their conduction imbalance/failure protective relays.

2.1 Power Supplies

Separate power supplies are employed for the AVR electronic circuits and the control pulse electronic circuits. Surprisingly both of the power supplies are unregulated; ie. dc output voltage levels vary

linearly with applied ac voltage magnitudes. Clearly the consequences of this were well understood by the manufacturer and a special control circuit is employed to connect a 24 Vdc battery to the control pulse electronics when generator terminal voltage drops below a preset level (initially commissioned at 60% of rated terminal voltage /1/). Zener diodes located on the other printed circuit boards are used to regulate the dc voltage used in level detection and comparator functions.

With the unit operating on test supply, the measurements listed in Table 2 were recorded. The high level of ac ripple in the control pulse unit supply outputs appeared suspicious and selected measurements were repeated on unit G1 with the generator on-line, operating at approximately rated terminal voltage. Measurements similar to those in Table 2 were obtained. It appears that the power supplies are operating as originally intended, although there are no specific guidelines provided in the manufacturer's literature /3/.

Table 2 ASEA EXCITER - MOUNTAIN CHUTE G2
POWER SUPPLY MEASUREMENTS

Supply Control Pulse Unit	Output Voltage (Vdc)	Ripple Voltage[1] (V peak-to-peak)
+24	24.7	0.9
-24	-26.3	0.05
+12	13.1	0.2
-12	-12.5	1.0
AVR Unit		
+24	26.2	0.1
-24	-27.8	-
+12	12.7	0.05
-12	-12.8	0.05

NOTE: (1) Primary ripple frequency = 360 Hz

2.2 Firing Circuitry

Two separate sets of control pulse circuits, each controlling three legs of each of the bridges, are used in this installation. Both sets are connected to the same AVR output signal. For the off-line tests, the unit was placed on test supply and the AVR output signal was disconnected and replaced with a variable dc supply. Varying this voltage over a range of ±8 Vdc varies the gate pulse delay angle over its full control range. Table 3 lists measurements of delay angle performed on one of the bridges for the extreme values of the input control voltage. Appendix A provides a reference diagram for ASEA's firing sequence nomenclature, along with definitions of the delay angle (α) and advance angle (β).

The delay angle measurements obtained with an input voltage of +8 Vdc correspond to the delay angle limit. For the original boards this value was approximately 20° for all six thyristors (the design value for this angle is 15° /3/). When the spare Control Pulse Generator card was installed in the slot controlling thyristors A, B, and C, the delay angle limit dropped to around 5° indicating that a problem exists with the comparison of the ac reference voltages on this board. It is noteworthy that the two other measurements of delay angle (V_{in} = 0 V and -8 V) were normal. Nevertheless, this spare board should not be used until the problems can be identified and repaired.

Table 3: MEASURED DELAY ANGLES - MOUNTAIN CHUTE G2

Thyristor	Firing Circuit Input (Vdc)	In-service Boards Delay Angle (Degrees)	Spare Board(1) Delay Angle (Degrees)
A	+8	19	7
	0	-	89
	-8	156	146
B	+8	19	4
	0	-	90
	-8	153	150
C	+8	23	3
	0	-	89
	-8	152	148
D	+8	20	-
	0	90	-
	-8	148	-
E	+8	20	-
	0	92	-
	-8	145	-
F	+8	19	-
	0	90	-
	-8	148	-

NOTE: (1) Spare board was Control Pulse Generator (QPTA 151) for Thyristors A, B, and C

The advance angle limit is obtained by subtracting the maximum delay angle (ie. V_{in} = -8 Vdc) from 180°. A properly set limit is important since it ensures that each thyristor is provided with sufficient time for commutation taking into account unequal phase shifts and other factors which may affect the firing circuitry. From Table 3 it can be seen that the limit is approximately 30° for each of the thyristors, which is reasonable as it corresponds to the maximum adjustable setting of the limit /3/.

Each thyristor is turned on by applying a 2 kHz oscillator output to the gate for the full 120° conduction period. Figure 3 is a measurement of the gate-to-cathode voltage on one of the thyristors on leg A along with its reference line-to-line voltage. The firing circuit input voltage was equal to +9 Vdc for this measurement, and the delay angle limit and 120° conduction period are indicated on the figure. The pulses applied to this thyristor have peak values of -1.3 V and 2.64 V. The range of acceptable pulse magnitudes /3/ is from -0.2 V to -1.4 V in the negative range and +1.5 V to +7 V in the positive range. The pulse voltages were measured on all 60 thyristors; in each case the pulses fell within the manufacturer's suggested range although many of them were at the lower end (ie. 1.8 to 2.5 V) and a number of them were very close to the lower positive limit (ie. 1.7 V to 1.8 V). The

local P&C staff should perform routine measurements of these pulses to determine whether there is an ongoing degradation of the control pulse distributors or thyristors. The manufacturer should be contacted to assess whether this is a potential source of intermittent failures given the thyristors characteristics.

2.3 Automatic Voltage Regulator

The generator potential-transformer connections to the AVR input were removed and a variable three-phase ac 115 Vrms supply was connected. The input voltage magnitude was varied and values of AVR output and delay angle were recorded (Table 4).

Table 4 AUTOMATIC VOLTAGE REGULATOR MEASUREMENTS[1]

Voltage[2] Input (Vrms)	Rectified Input (Vdc)	AVR Output (Vdc)	Delay Angle (Degrees)
114.6	-37.2	-8.06	152
113.4	-36.8	-5.61	134
112.4	-36.5	-2.80	114
111.3	-36.1	+0.25	92
109.7	-35.6	+4.00	66
108.7	-35.3	+6.70	44
105.6	-34.4	+8.9	-

(1) AVR reference input for these measurements was 5.6 Vdc
(2) Average value of the three line-to-line voltages

When operating within the limits, the relationship between the terminal voltage input magnitude and the AVR output is linear as expected. The relationship between the AVR output and delay angle is plotted in Figure 4, along with a calculated curve based on a cosinusoidal relationship between the two variables. The differences between the calculated curve and measured points is not critical in this design since, with the converter operating as an inverter, it is not possible to operate with a constant firing circuit input (ie. manual control). A manual control has been supplied with the exciter, however, it is only intended for use when the bridges are fed with an ac supply from a location other than the generator terminals.

The voltage regulator gain can be confirmed using a pair of measurements from Table 4 as follows:

$$K_A = \frac{\Delta E_{FD}(pu)}{\Delta E_t(pu)}$$

$$= \frac{E_{do}(\cos(44°) - \cos(134°)) / E_{FD\ (base)}}{(113.4 - 108.7) / 115}$$

With a maximum controlled converter voltage (E_{do}) of 540 Vdc (-1.35*400 V ac rms, ignores limits and commutation effects) and a base field voltage ($E_{fd\ (base)}$) of 108 Vdc, the calculated AVR gain

equals 170 pu E_{fd}/pu $E_{t\text{-}ref}$ which is very close to the calculated value listed in Table 1 for the gain switch position setting of three.

Once the calibration checks had been completed, the AVR output was examined on an oscilloscope. With the unit on test supply the ac ripple on the AVR signal was almost 1 V p-p and contained both 360 Hz and 60 Hz components. Measurements were also performed with the normal AVR input connections and the unit operating on open-circuit with essentially the same results. Figure 5 displays the AVR output, controlled converter output and terminal-voltage-feedback signal for open-circuit operation. Although the AVR output signal has a large ripple content, the effect on the controlled-bridge firing is acceptable. Increasing the filtering of the terminal-voltage feedback signal on this unit is not advisable, since the existing time constant (39 ms) is already approaching the upper acceptable limit for a fast-responding high-gain excitation system.

3. ON-LINE MEASUREMENTS

Since the off-line measurements failed to reveal any problems, a start-up was attempted to examine the unit's behaviour under normal operating conditions.

3.1 Battery Flashing

Figure 6 displays the result of a successful start-up of the unit. Terminal voltage increases smoothly and rapidly, reaching the preset level within three seconds. The battery is connected to the field for just over 1.2 seconds and supplies current to the generator field winding for approximately 1 second, after which the two bridges take over.

During the initial portion of the start-up, the controlled converter is operated as an uncontrolled rectifier with a constant 24 Vdc battery supplying the control pulse logic input in place of the AVR. The point at which the converter returns to controlled operation is determined by a terminal voltage comparator circuit referred to as a Low-Voltage Triggering Device by ASEA.

The original setpoint for this device corresponded to 60% of rated terminal voltage, which is after the AVR begins to function normally as the power supply voltages reach adequate levels (just above 30% of rated voltage based on Figure 6). From Figure 6 it is apparent that the comparator setpoint had increased to a level corresponding to almost 90% of rated terminal voltage. The reason for this change could not be explained as the potentiometer controlling the setpoint appears to have been left at its original value. A further drift in this setpoint could partially explain some of the unusual records obtained by P&C during previous start-up attempts in which the exciter output voltage did not follow the AVR output.

To correct this situation the voltage comparator was recalibrated off-line using an adjustable three-phase voltage supply. Table 5 lists the as-found and modified settings. There is ample hysteresis to ensure that the system does not switch between the controlled and uncontrolled modes during terminal voltage transients.

Table 5 LOW-VOLTAGE TRIGGERING DEVICE SET POINTS (G2)

	As-Found Setting[1] ac Voltage Input (%)[3]	New Setting[2] ac Voltage Input (%)
voltage increasing	86%	67%
voltage decreasing	58%	45%

NOTES:
(1) Potentiometer setting = 6/10
(2) Potentiometer setting = 7.5/10
(3) Average three-phase line-to-line voltages applied to unit, 19 V rms corresponds to 13.8 kV on the generator terminals

Figure 7 displays a start-up performed following the modifications to the Low-Voltage Triggering Device. The converter switches to controlled operation at the 67% level with only a small discontinuity in the output.

The setting for the triggering device on unit G1 remains at 6/10; during the next available unit outage the local P&C staff should measure its operating level and adjust it as required.

3.2 Open-Circuit Step Response Test

A switchable dc voltage supply was connected, through a 100 kΩ resistor, to the AVR summing junction at the same point as the stabilizer output. Step disturbances were introduced to the AVR input to study the dynamic response of the unit. Figure 8 displays a step test performed with the generator operating on open circuit at rated terminal voltage. The AVR gain computed from records similar to Figure 8 confirm the earlier calculations indicating a level of 180 pu E_{fd}/pu $E_{t\text{-}ref}$ with the gain switch set at position 3.

The magnitude of the step disturbance was gradually increased until the exciter output voltage ceilings were reached in both directions. Figure 9 displays the exciter output during both tests. Clearly there is negligible delay between the application of the input voltage change and the controlled bridge output voltage change. As expected the converter fires properly during transitions and when operating against both ceilings.

3.3 Power System Stabilizer Tests

The unit was synchronized to the system and loaded to efficiency to verify the operation of the power system stabilizer. Figure 10 displays the results of step disturbance tests performed with the stabilizer gain potentiometer set at 10/10 and 7/10 or 13.2 pu and 9.0 pu, respectively. As noted on this figure, unit G1 was also loaded above efficiency with its stabilizer turned on during these tests. Clearly the stabilizer does an excellent job of damping the unit's electromechanical oscillations following disturbances.

Examining the stabilizer output trace in Figure 10 it can be seen that there is a slight coupling between the terminal voltage and stabilizer output; ie. when the terminal voltage is increased (steady-state) the stabilizer output increases. This effect was identified during the original commissioning tests and was found to be due to a very small phase angle error within the Hall effect watt transducers

which produced small output changes during reactive power variations. This effect caused serious problems during the original operation of these stabilizers and a resistor-capacitor network was installed on the voltage inputs to the watt transducers for compensation (unit G2 only).

The sensitivity of the stabilizer output to reactive power changes was investigated further by varying the reactive power loading of the unit over a wide range while monitoring the stabilizer output signal. The changes in stabilizer output were not significant and did not continue to increase once the reactive power changes ended.

The values of the components in the compensating network were verified; they appear to be in good condition and do not require replacement.

4. MISCELLANEOUS MEASUREMENTS

A couple of problem areas were identified during the performance of some additional measurements.

4.1 AVR Reference Potentiometer

During the original commissioning tests /1/ on this unit, it was noted that the motor-operated voltage-adjusting rheostat was capable of creating large disturbances in AVR output, field voltage, generator terminal voltage and reactive power output due to poor wiper contact. Figure 11 shows a typical record, obtained with the unit operating on open circuit, in which large intermittent voltage variations occurred while lowering the terminal voltage via the reference rheostat. Unit G1 was found to have a similar problem, although it was not as severe.

The situation can be improved in the short term by simply cleaning the wiper contacts, however, the rheostats on both units should definitely be replaced with sealed units or a dual potentiometer arrangement as soon as possible.

4.2 Heat Sensitivity of Electronic Circuits

The front plates were removed from all of the control pulse and voltage regulator printed circuit boards. The unit was operated on open circuit at rated terminal voltage and a heat gun was used to raise the temperature of specific circuit boards. Temperature measurements were performed with a standard thermometer which was placed directly on the surface of the boards under test. A number of the circuit boards misbehaved quite badly when heated beyond a certain temperature. Figures 12 and 13 display disturbances which occurred during the heating of the AVR amplifier card (final stage, QFLD 105) and the control pulse amplifier card (QPTA 151). In the first of these tests the exciter protections operated to trip the unit. In the second test (Figure 13) the unit did not trip, however, observation of the controlled bridge output on an oscilloscope revealed that a number of thyristors did not fire during the peak temperature excursion.

The boards were heated to peak temperatures of 55°C; the maximum ambient temperature usually specified for excitation equipment in hydraulic installations is 40°C. It should be noted that the control electronic's cubicle is not ventilated and is directly adjacent to the thyristor bridge cubicle. Measurements performed immediately following a normal unit shutdown found the temperature between the circuit boards to be 35°C with an ambient temperature of just over 20°C.

A temperature related problem is consistent with the symptoms identified by the P&C staff, namely: intermittent failures during periods of full load operation in which no problem can be identified when the unit is restarted. Also, due to the nature of the problem, all, some or none of the exciter protection flags may be present after the unit has tripped.

To help determine whether temperature is a factor in the excitation system failures, a thermocouple will be installed in the electronic card frame and connected to existing monitoring equipment which has been used by the local P&C staff to capture records of previous system failures.

Similar problems at other stations have been rectified by providing some method of cooling, either convection or forced.

5. ADDITIONAL MEASUREMENTS - UNIT G1

On-line measurements were performed on unit G1 to confirm the correct operation of the exciter and power system stabilizer. Figure 14 displays the results of a step disturbance test performed with the unit loaded to 70 MW and the stabilizer in service. As was the case with unit G2, the electromechanical oscillations are well damped with the stabilizer operating at the normal in-service gain setting.

Terminal voltage and reactive loading were gradually reduced while observing the stabilizer output signal. Although there was virtually no coupling between reactive power and stabilizer output on this unit, another problem was encountered. When the incoming reactive power exceeded 25 MVAR, large swings appeared in the exciter output voltage (and consequently all other quantities). Figure 15 shows the occurrence of these oscillations as the terminal voltage was lowered and then raised through the threshold (above 12 kV). From Figure 15 it can be seen that the frequency of oscillation is approximately 6 Hz and that the swings in the controlled rectifier output voltage reach levels in excess of 800 V peak-to-peak. The oscillations in the controlled converter output appear to be due to some form of limit cycle rather than an unstable resonance; the oscillations quickly build up to a constant level and appear to be limited just below the ceiling voltage limits of the controlled converter.

During the original commissioning tests /1/, both units were found to operate satisfactorily at low terminal voltage levels (11.0 kV). In addition a test was previously performed on unit G2 which demonstrated that operation with only 9 Adc of field current produced no erratic or discontinuous behaviour (0 MW, -63 MVAR, 11.0 kV). Current tests on open circuit confirmed that unit G2 operates properly to the lower limit of its AVR adjustment range (ie. 80% of rated voltage or just above 11.0 kV).

To study the phenomenon on G1 more closely, the generator was placed on open circuit and a number of tests were performed. Although the direct cause of the oscillations could not be determined, the following control systems were eliminated as potential suspects:

- power system stabilizer - with the generator operating on open circuit and with the stabilizer disconnected from the AVR, the unit began to oscillate when the voltage was lowered below 12.4 kV.
- rotor current limiter - the output of this circuit was monitored to ensure that it did not operate during the oscillations.
- under-excited current limiter - this circuit is disconnected from the AVR.
- selector (commonly referred to as auctioneer) - this circuit did not appear to influence the oscillations as both the input and output signals vary together.
- low voltage triggering device - the output of this device was monitored to ensure that it did not operate during the oscillations.

The field current level at the onset of the oscillations is approximately 600 Adc or 120 Adc per thyristor bridge. Obviously thyristor conduction problems due to low field current levels are not a factor in this problem. Figure 16 is a high-speed chart recording of the oscillations occurring with the unit operating on open circuit at a terminal voltage level of just under 12.4 kV. Field current, AVR output and the 12 Vdc AVR power supply were also recorded for reference. Figure 17 is an oscilloscope trace of the controlled converter output and uncontrolled bridge output during one of the oscillations which clearly shows that all legs of the bridge are firing correctly.

In a high gain closed-loop system such as the generator/AVR loop, it is difficult to establish cause-and-effect relationships between the various variables. Unfortunately, since this unit cannot be operated on manual control (ie. fixed field voltage), when the converters are fed from the generator terminals, it was not possible to directly establish the effect of the AVR on this problem. The AVR gain was reduced from its normal setting of 180 pu E_{fd} / pu $E_{t\text{-}ref}$ (switch setting = 3) to 80 pu (switch setting = 1). When the unit was returned to service the oscillations occurred at approximately the same terminal voltage level although the frequency of oscillation had dropped to approximately 5 Hz and the magnitude of the controlled converter swings was reduced to 600 V peak-to-peak (see Figure 18).

Further analysis and testing will be required to determine the source of these oscillations. Future tests might require that the unit be operated with a separate supply of alternating current to both the converter bridges and the electronic power supplies. This would allow proper measurement of the effect of terminal feedback through the AVR and coupling through the poorly regulated power supplies.

6. CONCLUSIONS AND RECOMMENDATIONS

With the exception of the problems with the AVR reference rheostat, the exciter on unit G2 appeared to be operating normally during, and immediately following, the tests. However, given the age of these exciters, a high level of reliability cannot be guaranteed in the future, particularly since some of the spare printed circuit boards are faulty. Therefore some consideration should be given to replacing each of these exciters, or as a minimum, the electronic control circuits (ie. power supplies, AVR, field current limiter and firing pulse control circuitry). In the interim period the following work should be performed by the local P&C staff to help improve the reliability of unit G2:

- Replace the AVR reference rheostat with a sealed unit or a dual potentiometer arrangement.
- Install a thermocouple in the exciter electronics card cage and monitor temperature along with various exciter variables on the existing monitor which has been used on this unit. Should future problems occur which appear to be related to the temperature inside the electronic's cubicle, some form of cooling should be arranged.
- Perform routine measurements of the various exciter quantities on a regular basis (eg. every three months) to identify any emerging problems.
- Contact the manufacturer to obtain more specific information on the thyristor gate pulse requirements.

The problem identified on unit G1 should be addressed promptly. Until it can be resolved, the operating staff should observe a minimum operating terminal voltage limit of 12.5 kV. Further tests should be scheduled to determine the source of the problem and to implement and test a solution. The local P&C staff should also test and reset, if necessary, the Low-Voltage Triggering Device on Unit G1.

6.1 Acknowledgements

The technical assistance of Fred Hartwick and Barry LaBrie of Renfrew District P&C and the work of Bruno Pietrantonio of the System Studies Section, Electrical Research Department, during the tests and preparation of this report are gratefully acknowledged.

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Appendix A

FIRING SEQUENCE REFERENCE AND DEFINITIONS
ASEA CONVERTER

The firing sequence, defined according to ASEA's thyristor numbering shown in Figure A1, is ADBFCE. Measurement of the delay angle, α, is illustrated in Figure A1 for thyristor A. With reference to line-to-line voltage V_{RW}, α is the angle between the beginning of conduction of thyristor A and the point at which V_{RW} becomes the most positive line-to-line voltage (ie. the earliest point at which thyristor A may fire). The advance angle, β, is the angle between the beginning of conduction of thyristor A and the point at which V_{RW} becomes the most negative line-to-line voltage (ie. the latest point at which thyristor A may fire assuming instantaneous commutation).

Figure A1 displays firing pulse positions and the resulting bridge output voltage for operation with a delay angle of 60° and negligible commutation.

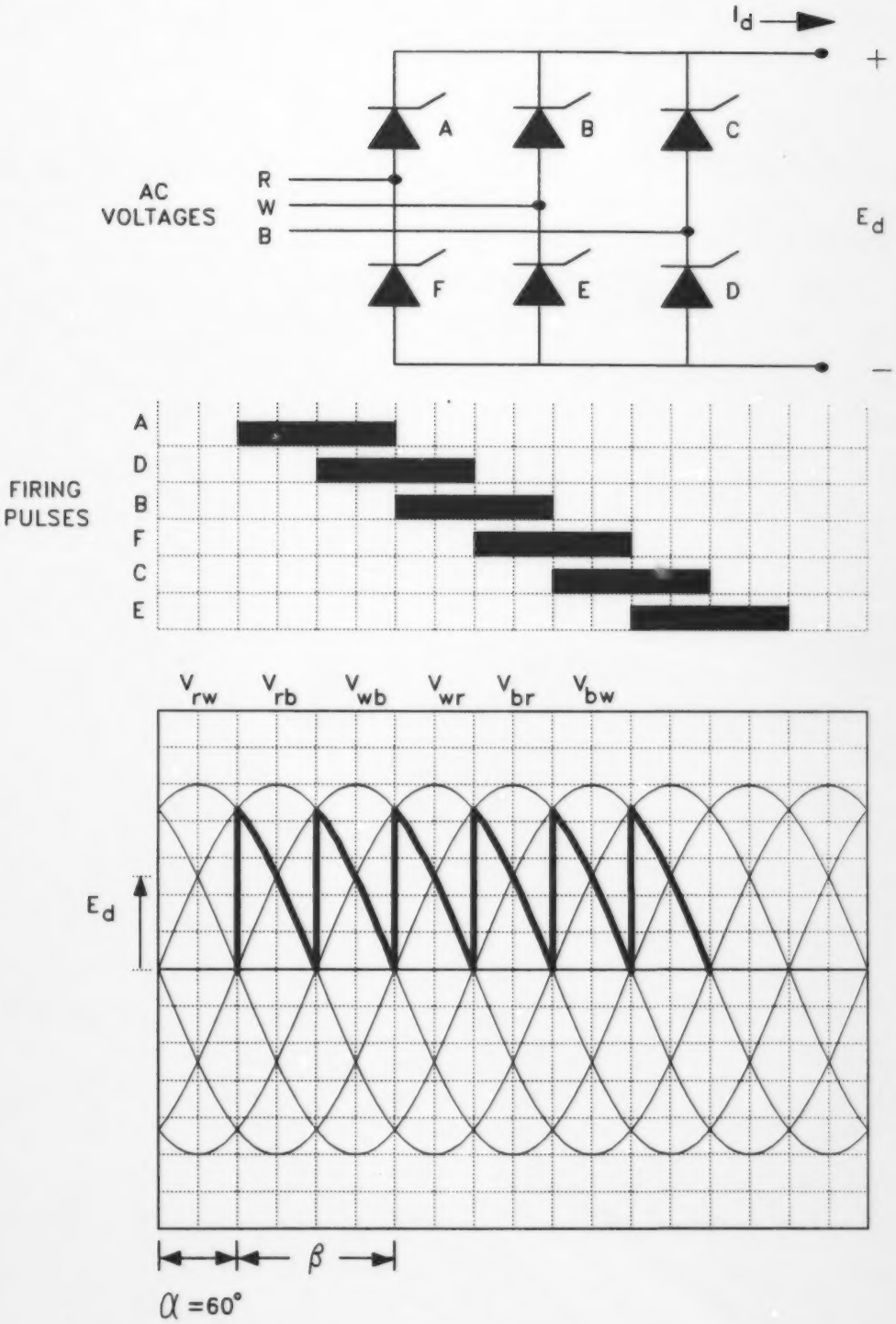

FIGURE A1: OPERATION WITH DELAY ANGLE OF 60 DEGREES AND NEGLIGIBLE COMMUTATION

CHUTEA1.DRW

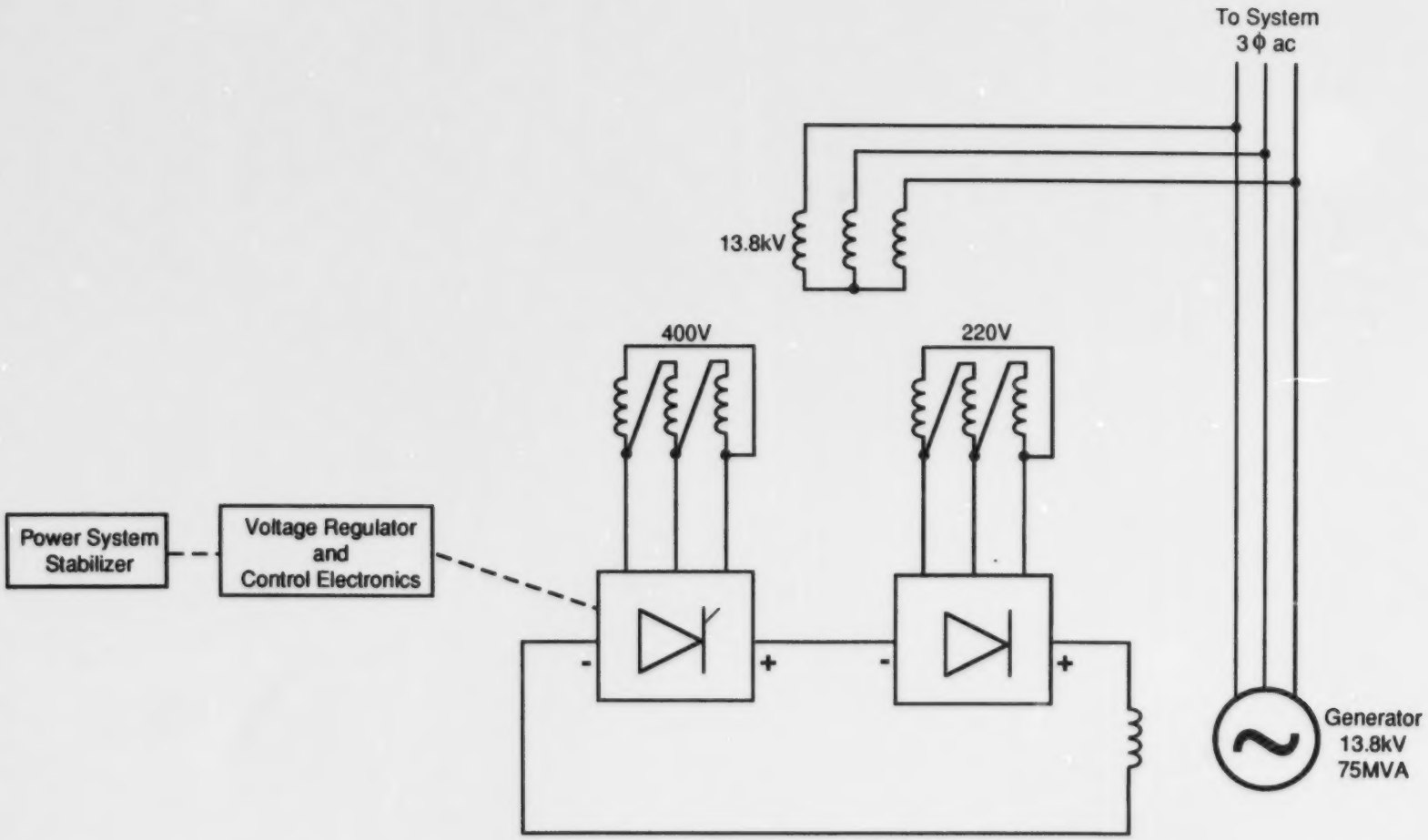

FIGURE 1

SIMPLIFIED SCHEMATIC OF MOUNTAIN CHUTE GS EXCITATION SYSTEM

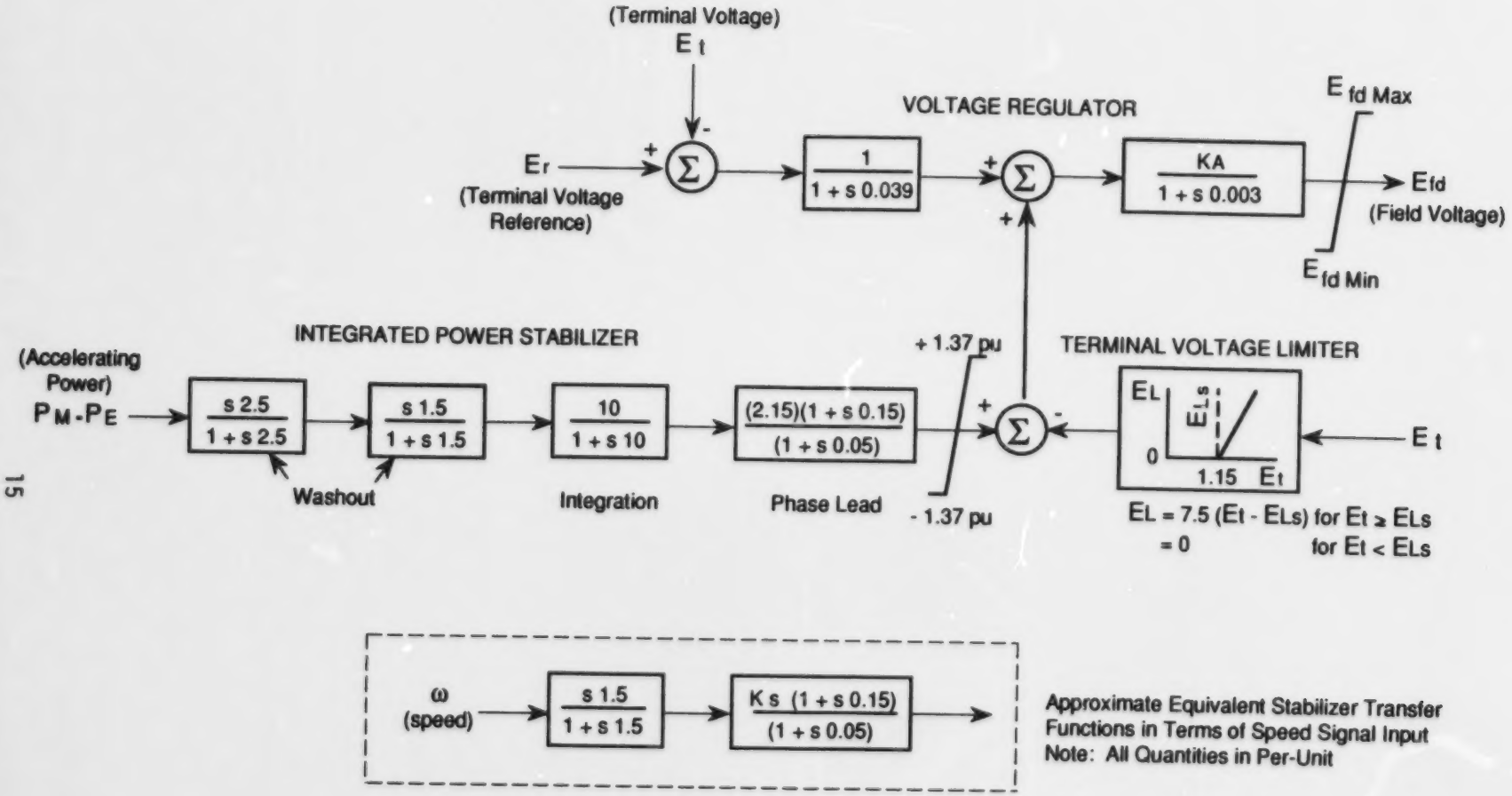

FIGURE 2

BLOCK DIAGRAM OF VOLTAGE REGULATOR AND INTEGRATED POWER STABILIZER
MOUNTAIN CHUTE GS - UNITS 1 AND 2

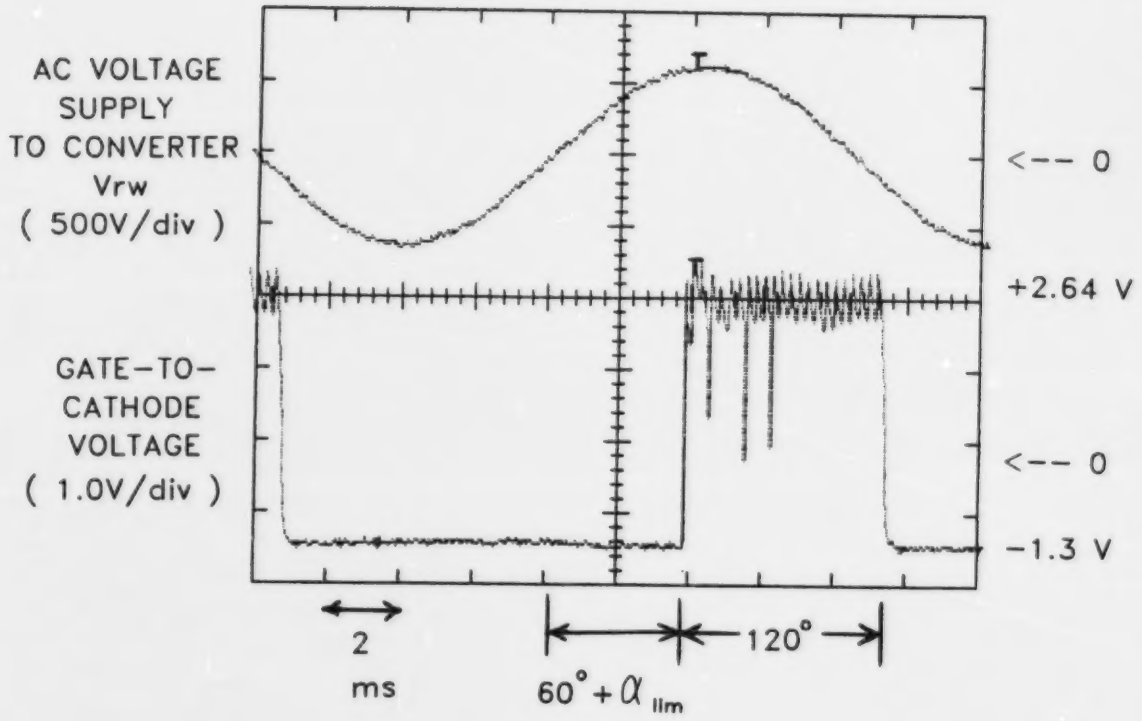

FIGURE 3 : MEASUREMENT OF GATE VOLTAGE WITH UNIT ON TEST SUPPLY, THYRISTOR 3A BRIDGE #7, MTN CHUTE G2, MARCH 1991

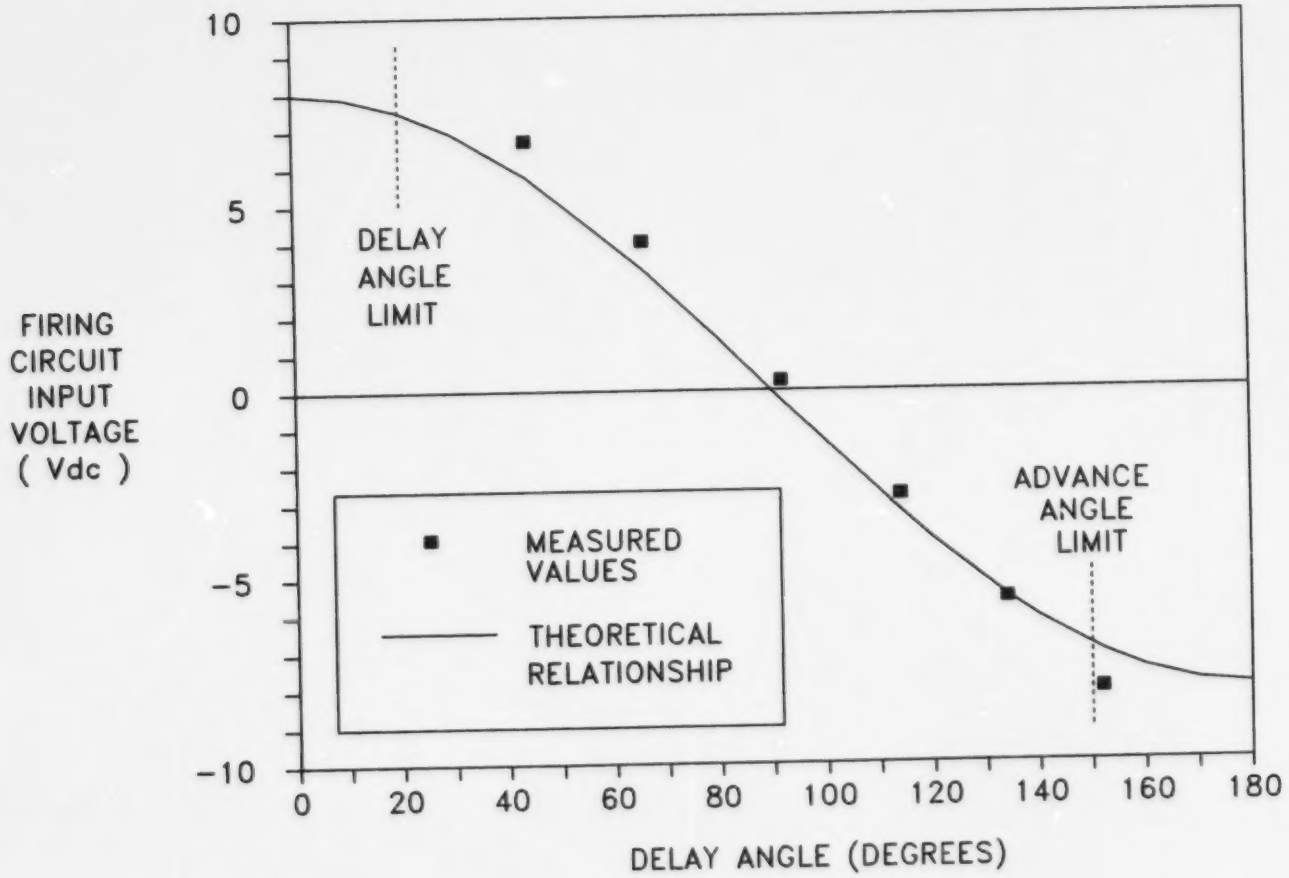

FIGURE 4 : RELATIONSHIP BETWEEN FIRING CIRCUIT INPUT VOLTAGE AND DELAY ANGLE – MOUNTAIN CHUTE G2

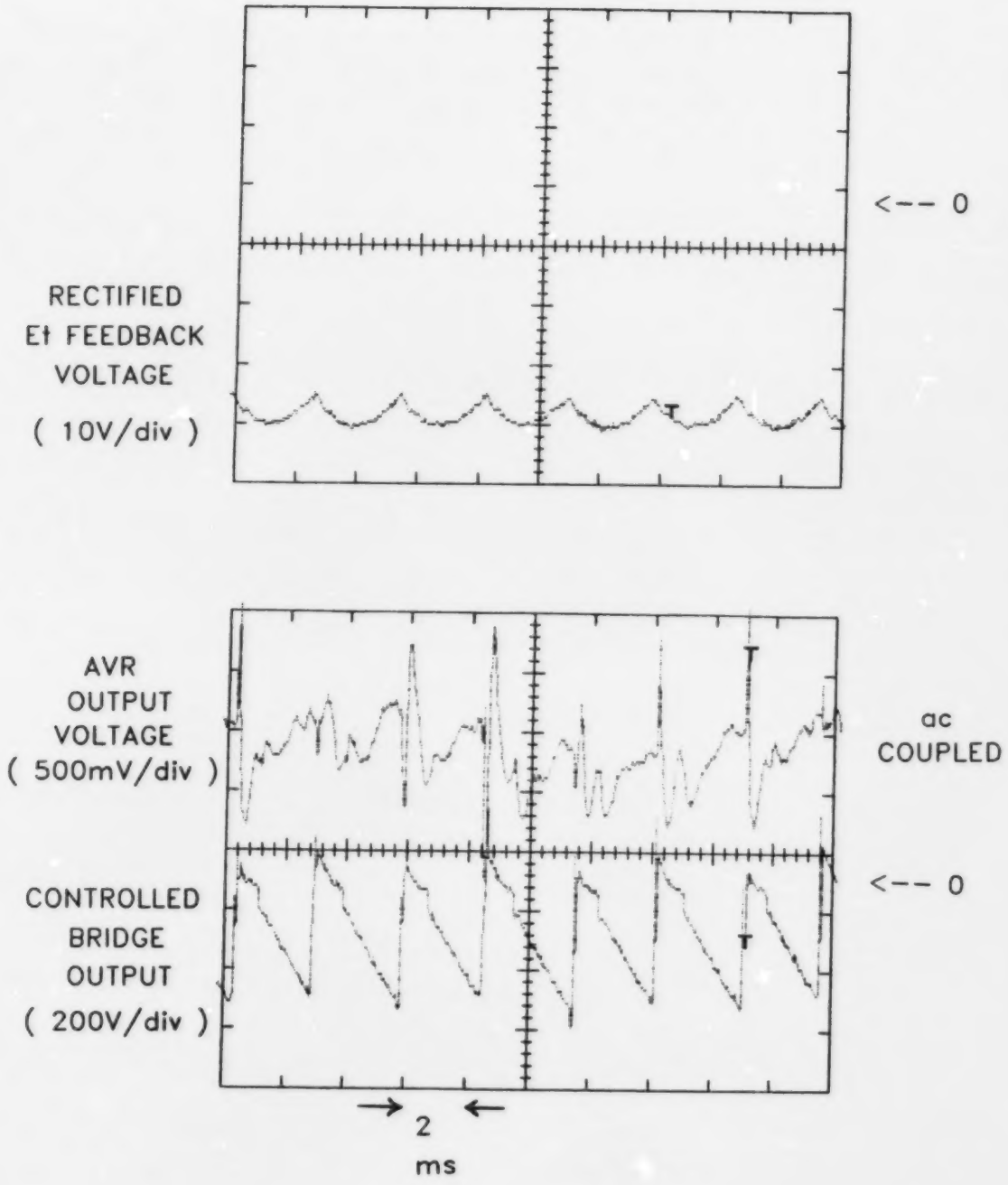

FIGURE 5 : VOLTAGE REGULATOR AND BRIDGE OUTPUT SIGNALS, MOUNTAIN CHUTE G2 MARCH 1991

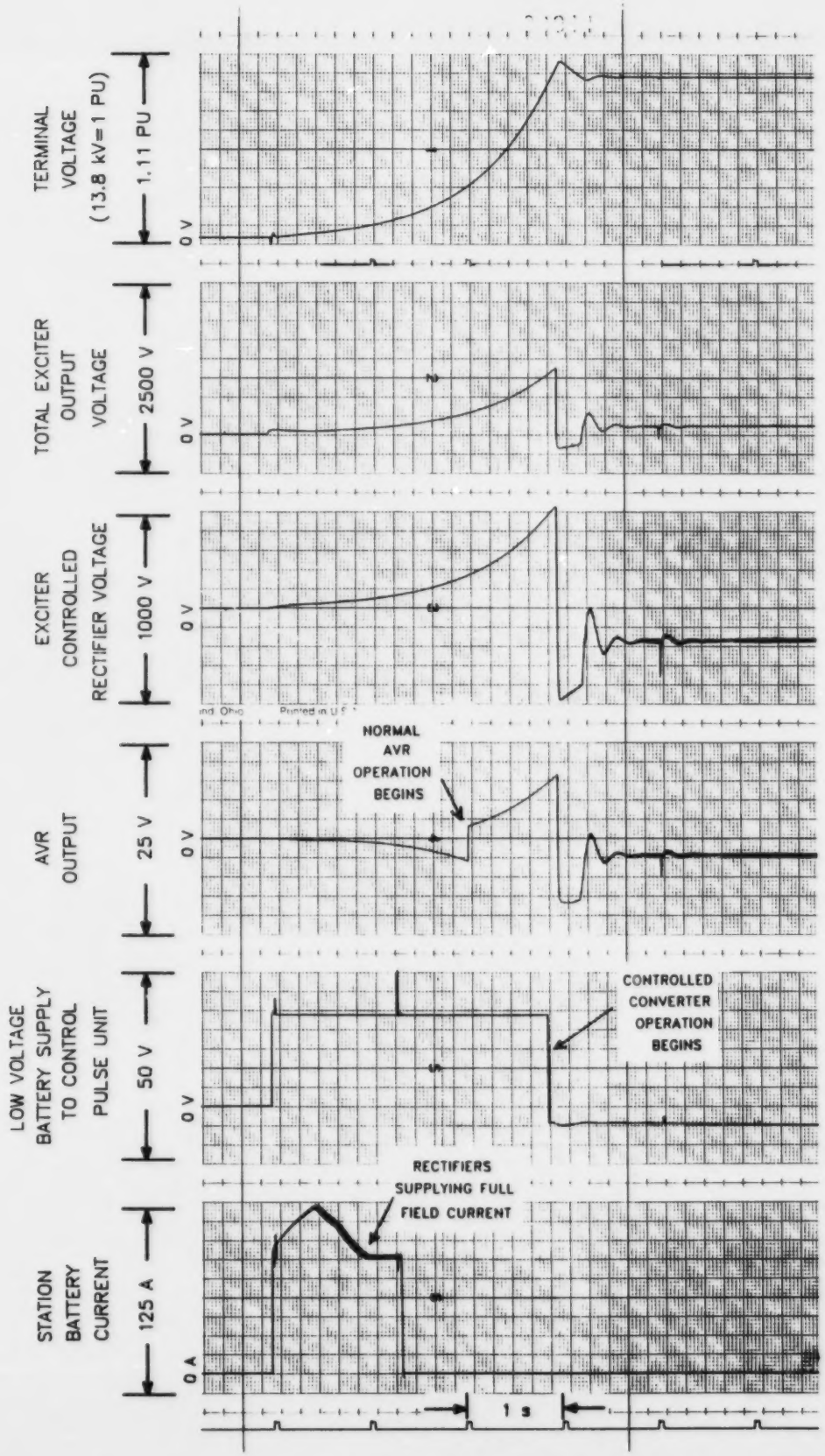

FIGURE 6: MOUNTAIN CHUTE GS, G2 EXCITATION SYSTEM TESTS
UNIT START UP MARCH 27/91

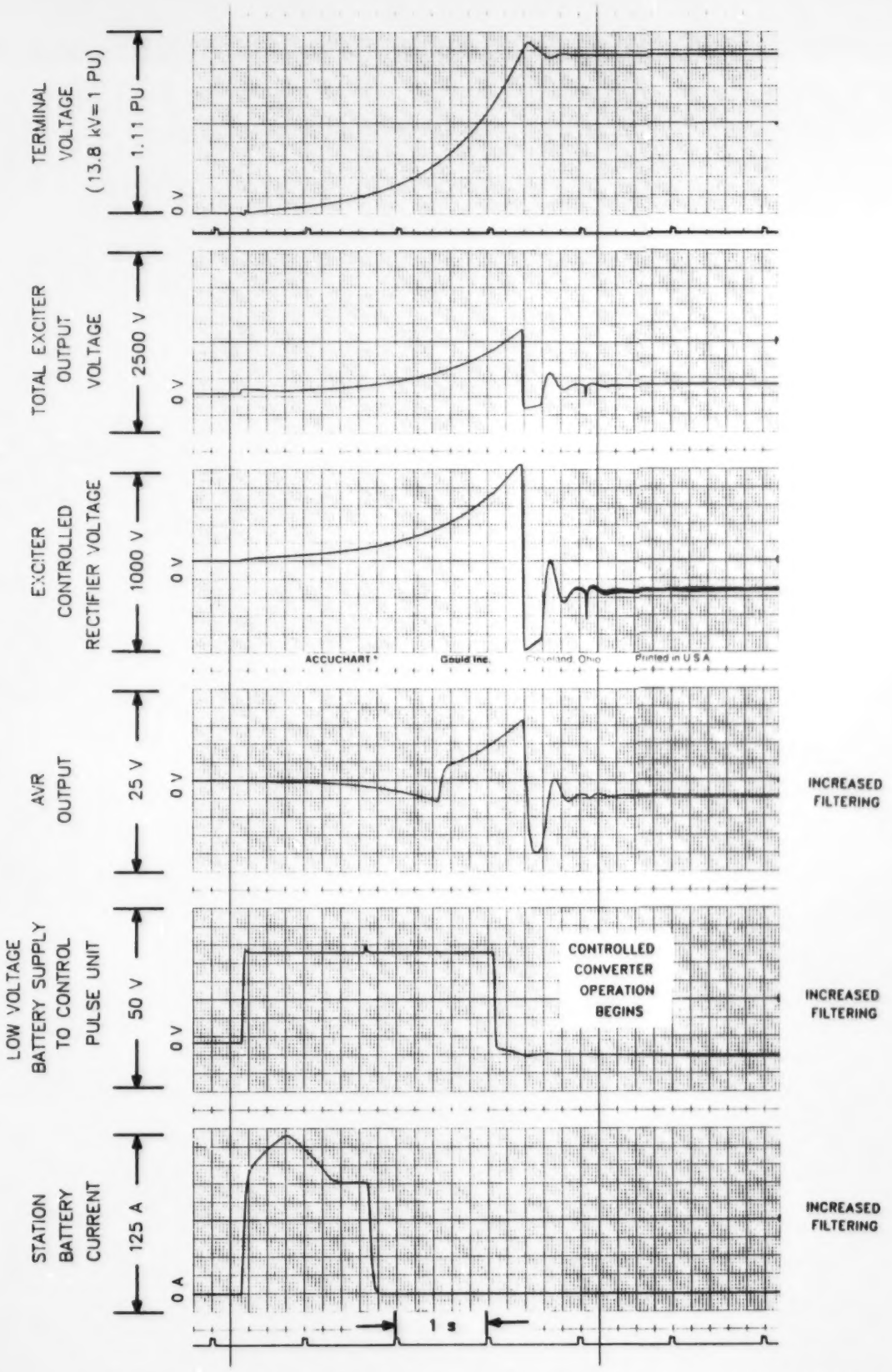

FIGURE 7: MOUNTAIN CHUTE GS, G2 EXCITATION SYSTEM TESTS
UNIT START UP AFTER ADJUSTMENT OF LOW SUPPLY VOLTAGE TRIGGERING DEVICE
MARCH 27/91

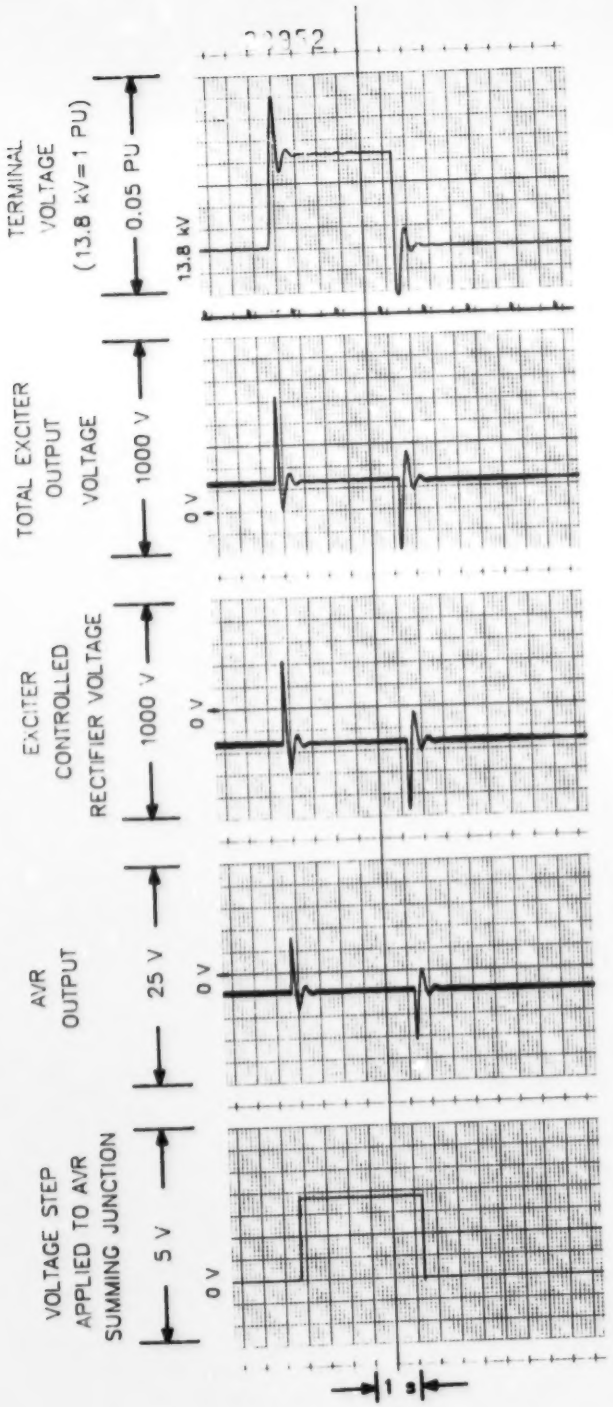

FIGURE 8: MOUNTAIN CHUTE GS, G2 EXCITATION SYSTEM TESTS
OPEN CIRCUIT STEP RESPONSE TEST, AVR GAIN SWITCH = 3
MARCH 27/91

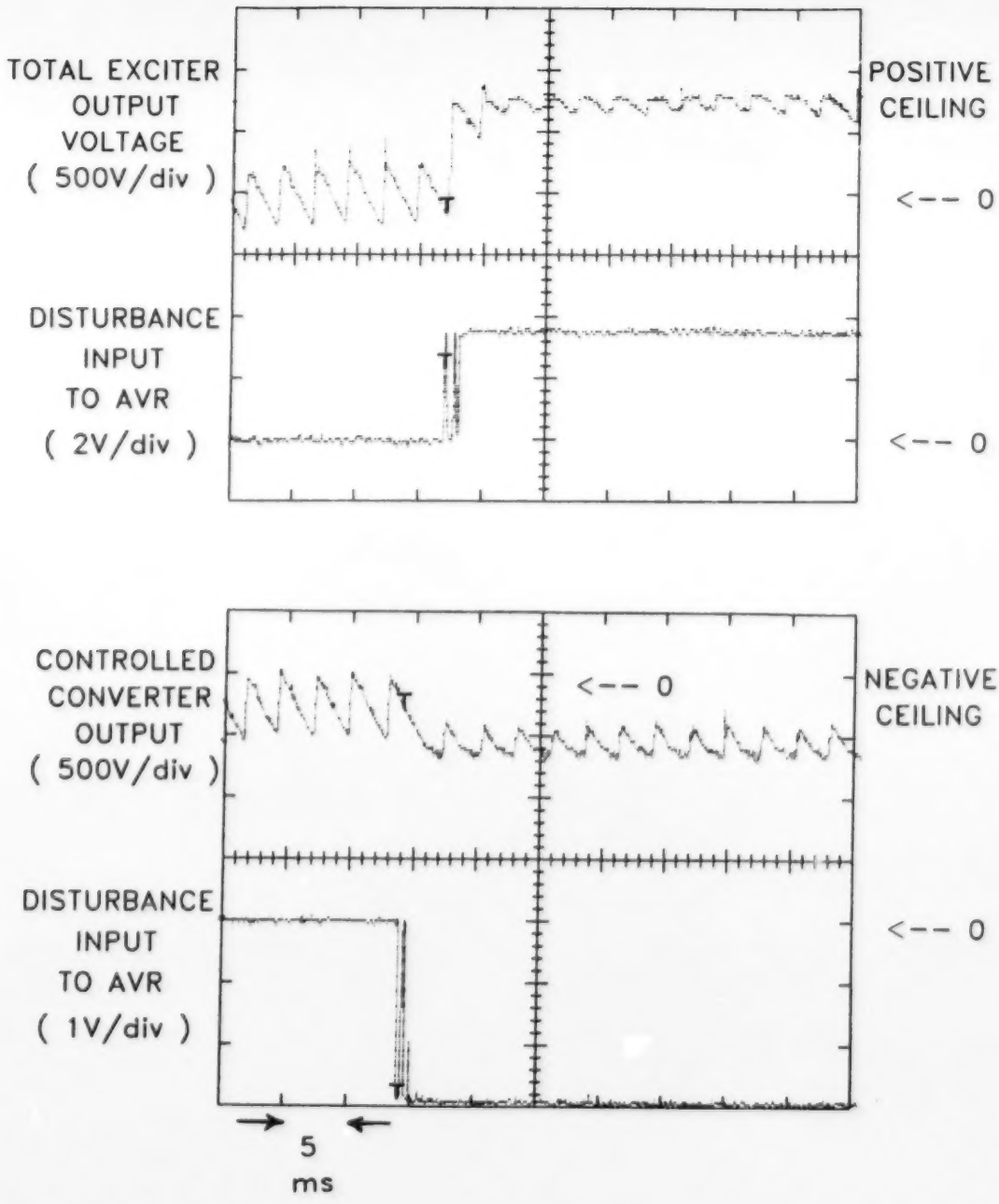

FIGURE 9 : MEASUREMENTS OF FIELD VOLTAGE CEILINGS, MOUNTAIN CHUTE G2

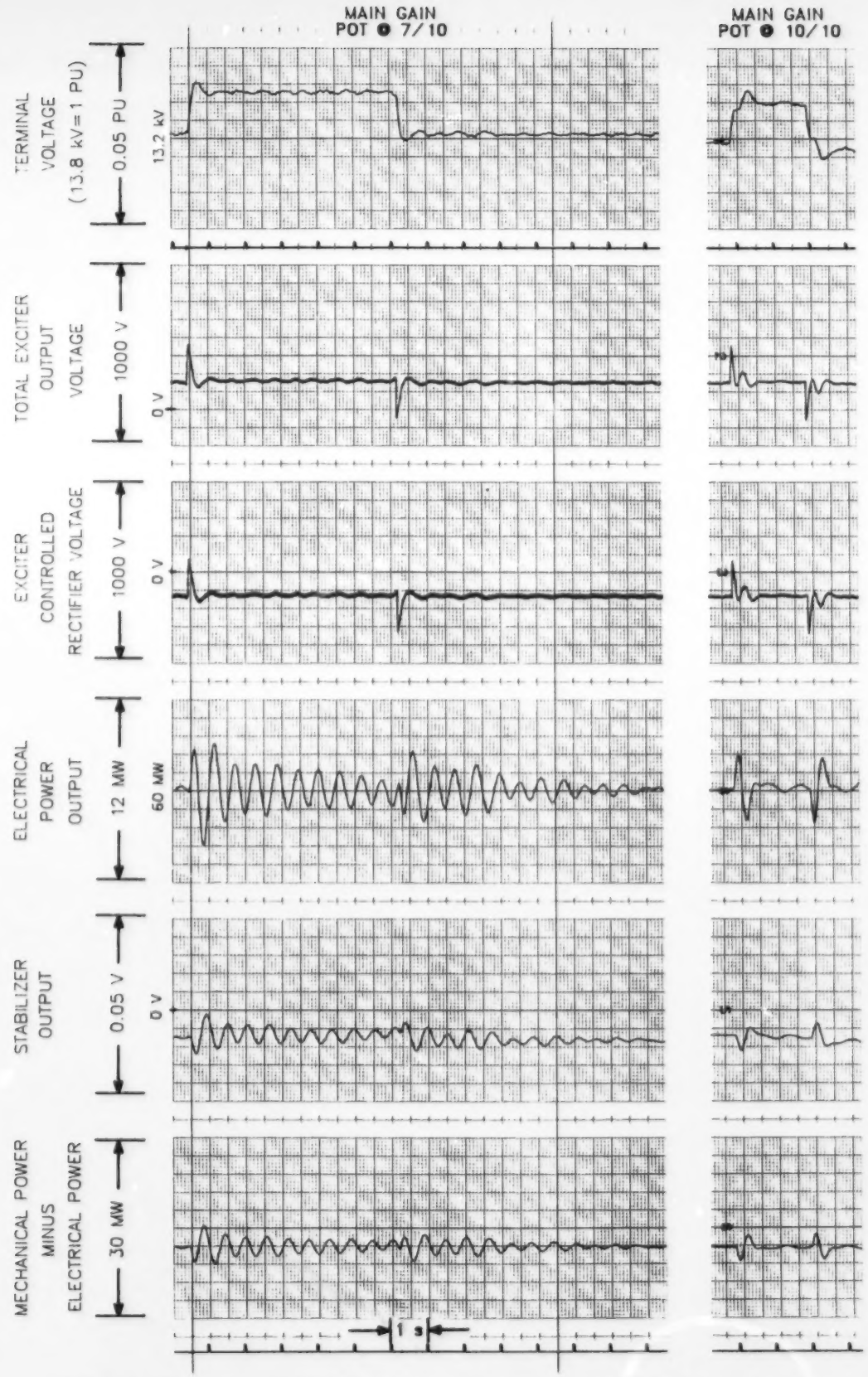

FIGURE 10: MOUNTAIN CHUTE GS, G2 EXCITATION SYSTEM TESTS
STEP RESPONSE TESTS: G1 @ 69 MW, 7 MX out, G2 @ 60 MW, 3 MX out
MARCH 27/91

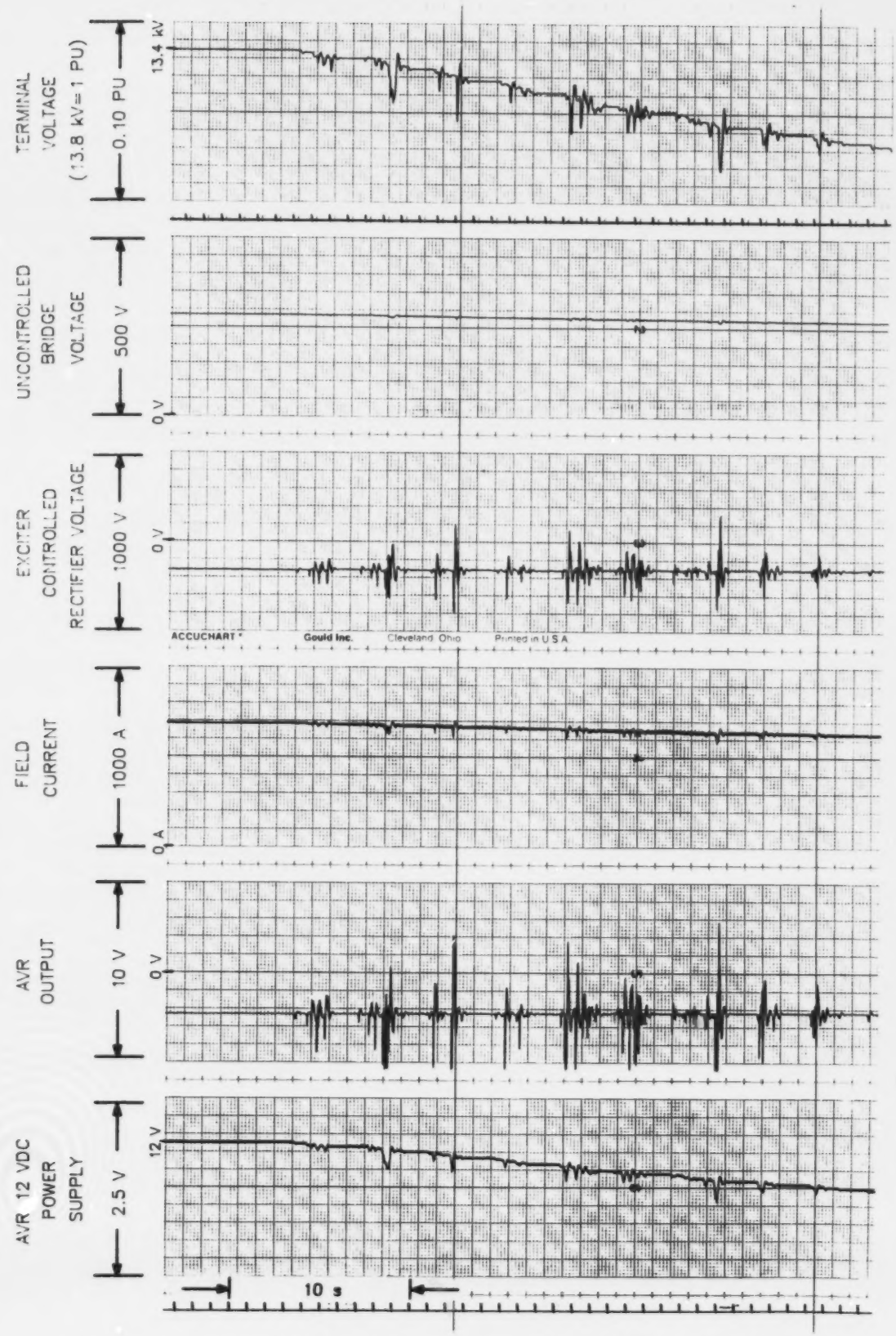

FIGURE 11: MOUNTAIN CHUTE GS, G2 EXCITATION SYSTEM TESTS
VOLTAGE VARIATIONS INTRODUCED BY AVR SETPOINT
RHEOSTAT MOVEMENT MARCH 27/91

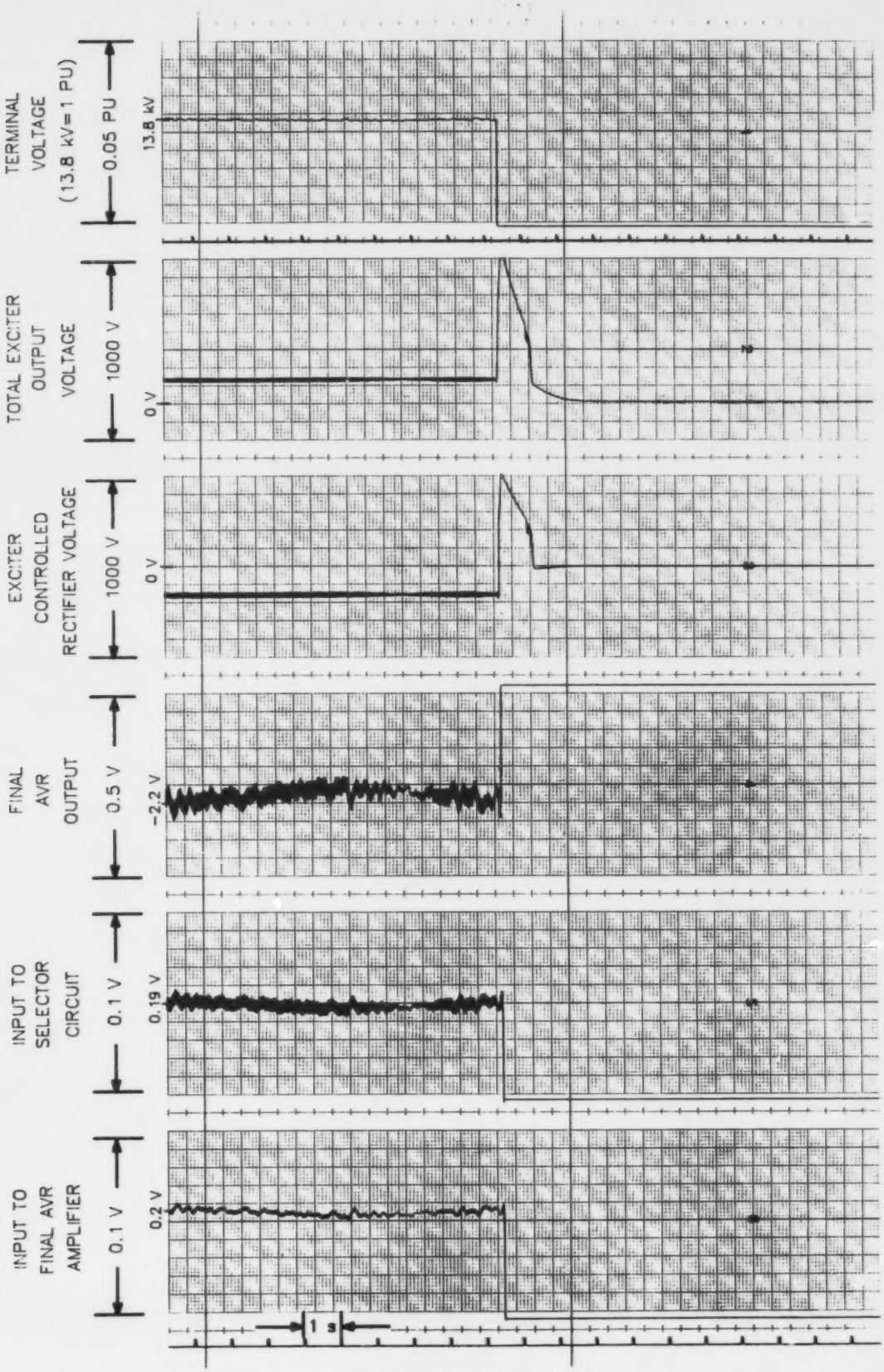

FIGURE 12: MOUNTAIN CHUTE GS, HEAT TEST
UNIT OPERATING ON OPEN CIRCUIT, HEATING FINAL AVR AMPLIFIER CARD (QFLD105) MARCH 27/91

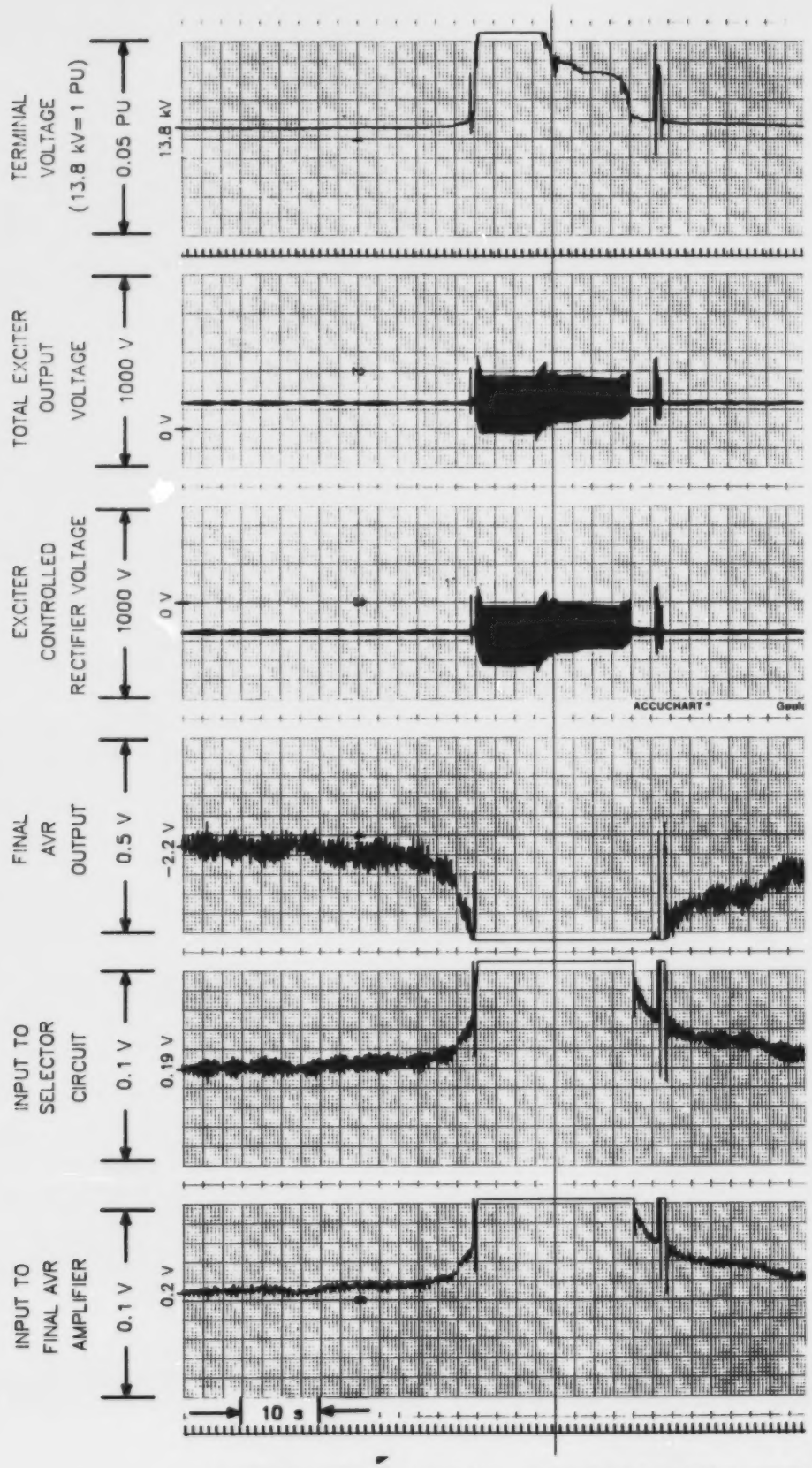

FIGURE 13: MOUNTAIN CHUTE GS, HEAT TEST
UNIT OPERATING ON OPEN CIRCUIT, HEATING CONTROL PULSE AMPLIFIER CARD (QPTA 151) MARCH 27/91

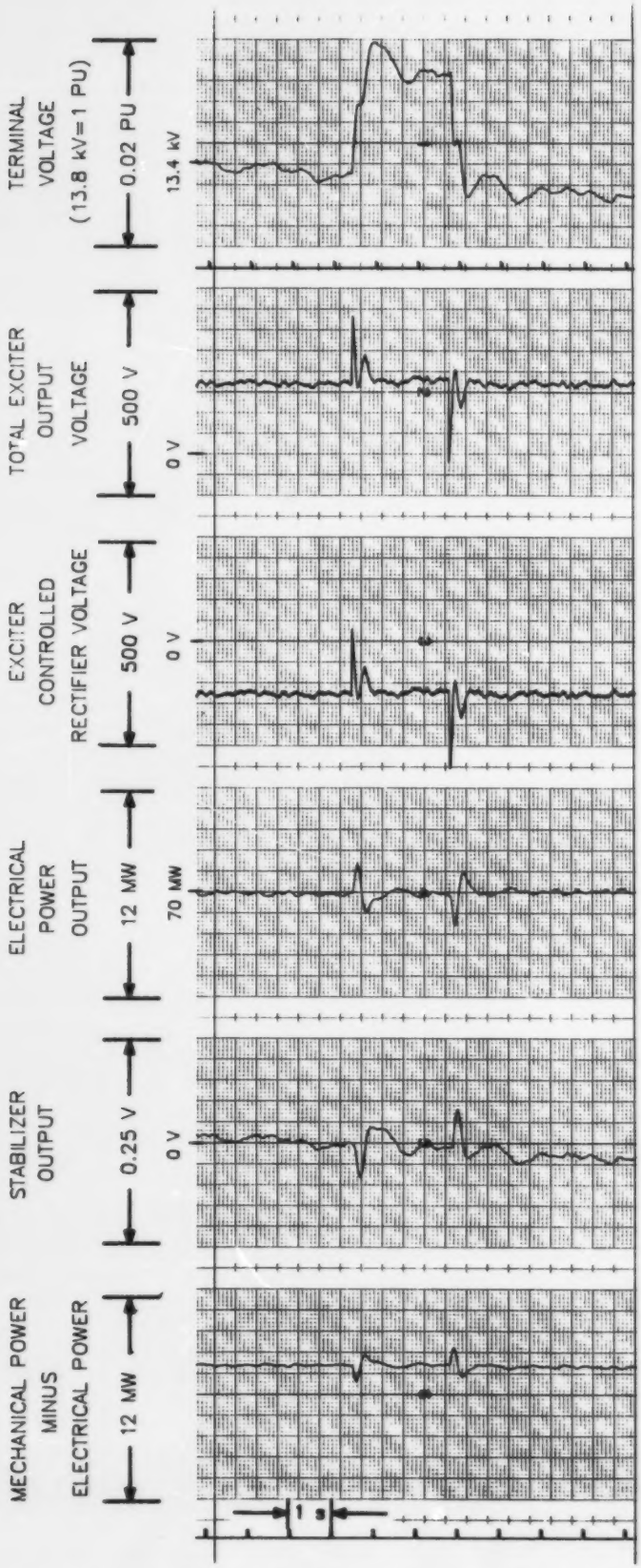

FIGURE 14: MOUNTAIN CHUTE GS, G1 EXCITATION SYSTEM TESTS
STEP RESPONSE TESTS: G1 @ 70 MW, 13 MX out, G2 @ 69 MW, 3 MX out
MARCH 27/91

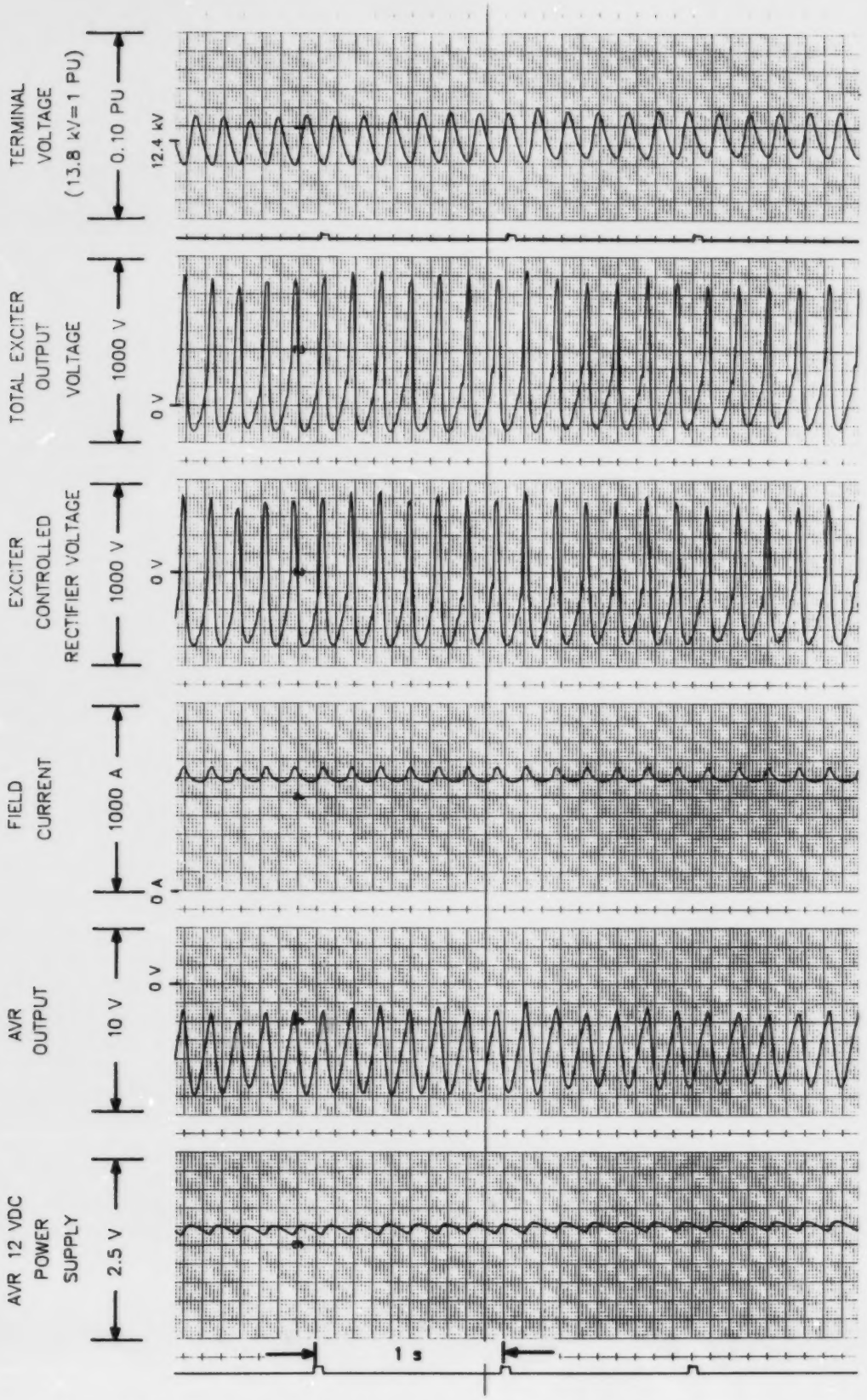

FIGURE 16: MOUNTAIN CHUTE GS, G1 EXCITATION SYSTEM TESTS
VOLTAGE OSCILLATONS OCCURRING DURING OPERATION AT
LOW TERMINAL VOLTAGE ON OPEN CIRCUIT , MARCH 27/91

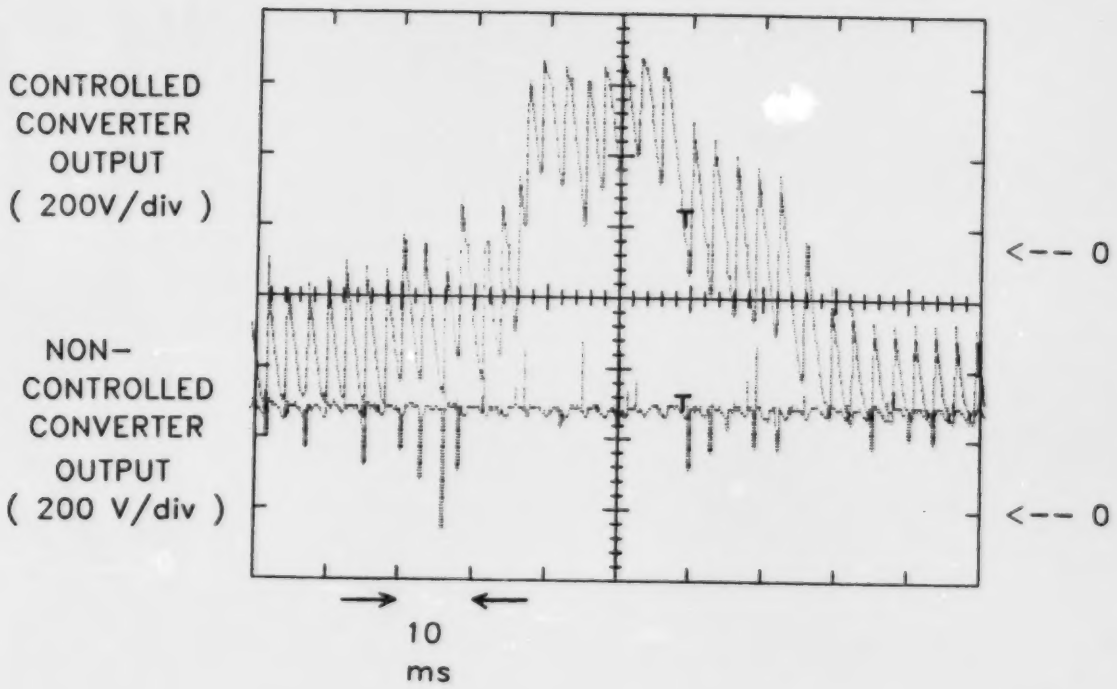

FIGURE 17 : EXCITER OUTPUT VOLTAGES DURING LOW VOLTAGE OPEN CIRCUIT OPERATION ON MOUNTAIN CHUTE UNIT G1

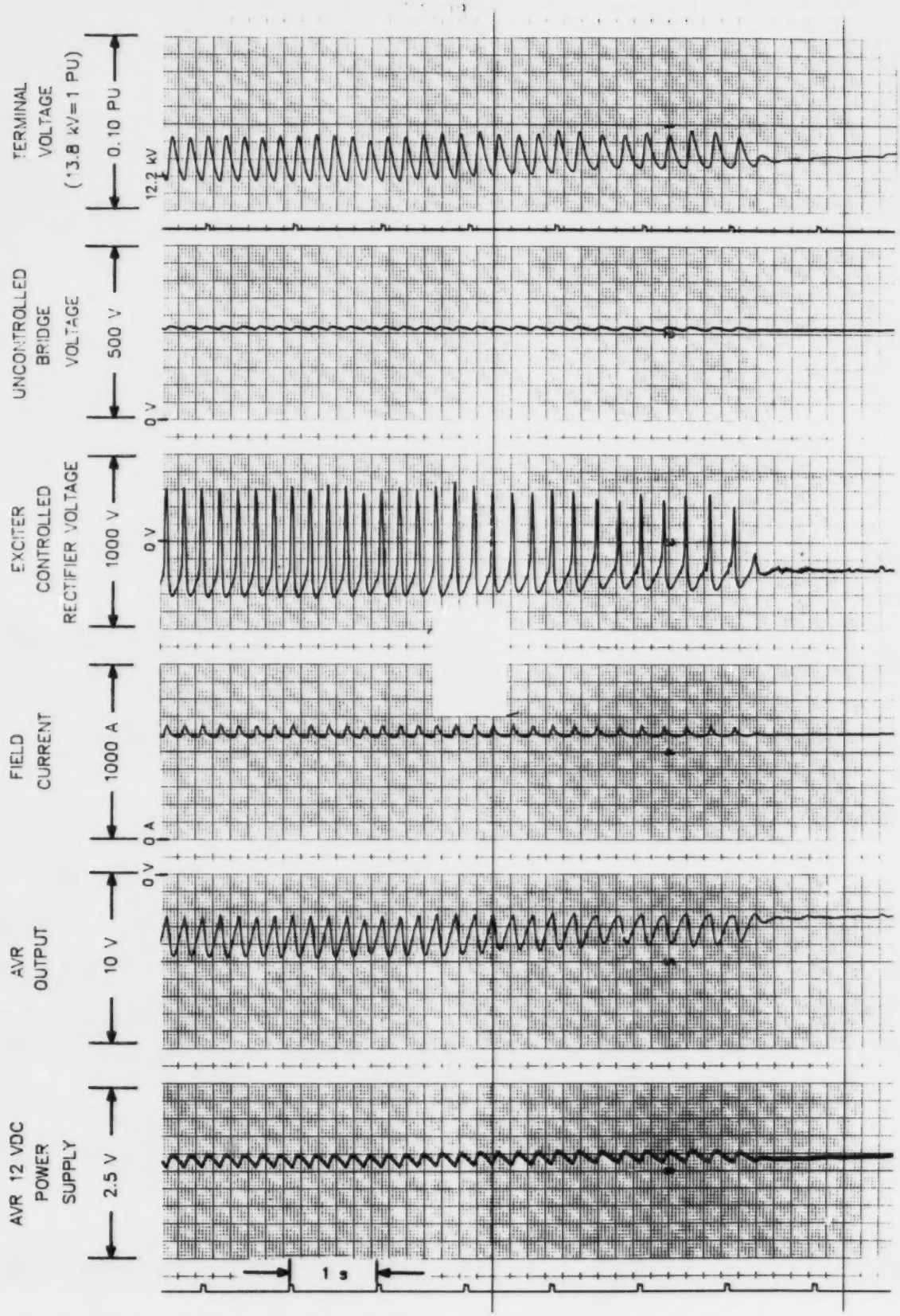

FIGURE 18: MOUNTAIN CHUTE GS, G1 EXCITATION SYSTEM TESTS
OSCILLATONS AT REDUCED VOLTAGE ON OPEN CIRCUIT
WITH LOWER AVR GAIN = 80 PU , MARCH 27/91